NUMERICAL SIMULATIONS ON THE EFFECTS OF USING VENTILATION FAN ON CONDITIONS OF AIR INSIDE A CAR PASSENGER COMPARTMENT

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To my beloved…
father, Sabri bin Abdullah
mother, Rebeah bt Hj. Harun
brothers, sisters-in-law,
nieces and my nephews.

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In the name of Allah, the Most Gracious and the Most Merciful

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ABSTRACT

The use of a mechanical ventilation fan is one strategy that can be employed to reduce high air temperature build up in a car passenger compartment when it is parked in the sun. This study developed a numerical simulation to investigate the effects of using a ventilation fan on the air temperature inside the passenger compartment when it is parked in the open space during a sunny day. A computational fluid dynamics (CFD) method was used to perform the numerical simulations. FLUENT software was employed to develop the passenger compartment model and simulate the air flow conditions inside the passenger compartment. The validation of the numerical simulation was done by comparing the air temperatures from the CFD simulation results against the air temperatures at two selected points obtained from the field measurement from 12 pm to 3 pm. On average, the air temperature prediction at the front and rear compartment show good agreement with the measured data, with a difference of about 2.5% and 1.6%, respectively. The validated numerical simulation was used to perform a parametric study to investigate the effects of the ventilation fan location, number of the ventilation fans as well as the air velocity at the ventilation fans, on the air temperature and air flow pattern inside the passenger compartment. A three-dimensional (3D) steady–state simulation results show that placing one ventilation fan at the rear deck with an air velocity of 2.84 m/s reduces the air temperature at the front and rear compartment by 4°C. Placing four ventilation fans at the roof lowers the air temperatures at the front and rear compartments by 6°C and 7°C, respectively. Increasing the air velocity from 2.84 m/s to 15.67 m/s at four ventilation fans placed at the roof suggests the highest reduction of the air temperature inside the passenger compartment by 8°C.

ABSTRAK

Penggunaan kipas pengudaraan mekanikal merupakan satu strategi yang boleh digunakan untuk mengurangkan suhu udara yang tinggi di dalam ruang penumpang sebuah kereta apabila ianya diletakkan di bawah sinaran matahari. Kajian ini membangunkan simulasi berangka untuk menyiasat kesan–kesan penggunaan kipas pengudaraan terhadap suhu udara di dalam ruang penumpang sebuah kereta apabila ianya diletakkan di kawasan terbuka pada hari yang panas terik. Kaedah Perkomputeran Dinamik Bendalir Berbantukan Komputer (CFD) digunakan untuk melakukan simulasi berangka. Perisian FLUENT digunakan untuk membangunkan model ruang penumpang dan mensimulasi keadaan aliran udara di dalam ruang penumpang. Pengesahan simulasi berangka telah dilakukan dengan membandingkan suhu udara daripada simulasi berangka dengan suhu udara pada dua titik yang diperolehi daripada pengukuran sebenar daripada pukul 12 tengahari hingga 3 petang. Secara purata, ramalan suhu udara pada ruang hadapan dan belakang menunjukkan persetujuan yang baik dengan data yang diukur, dengan perbezaan masing-masing adalah sebanyak 2.5% dan 1.6%. Simulasi berangka yang telah disahkan digunakan untuk melaksanakan kajian parametrik untuk menyiasat kesan-kesan lokasi kipas pengudaraan, bilangan kipas pengudaraan dan juga halaju udara pada kipas pengudaraan, ke atas suhu udara dan corak aliran udara di dalam ruang penumpang. Keputusan simulasi keadaan mantap tiga dimensi (3D) menunjukkan bahawa meletakkan satu kipas pengudaraan pada dek belakang dengan halaju udara 2.84 m/s mengurangkan suhu udara pada ruang hadapan dan belakang sebanyak 4°C. Meletakkan empat kipas pengudaraan pada bumbung menurunkan suhu udara pada ruang hadapan dan belakang masing-masing sebanyak 6°C dan 7°C. Peningkatan halaju udara pada empat kipas pengudaraan yang diletakkan pada bumbung daripada 2.84 m/s kepada 15.67 m/s menunjukkan pengurangan suhu udara tertinggi di dalam ruang penumpang iaitu sebanyak 8°C.

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NOMENCLATURE

Roman Symbols

D	-	Diameter	(cm)
υ	-	Air velocity	(m/s)
k	-	Turbulence kinetic energy	(m^2/s^2)
t	-	Time	(s)
p	-	Static pressure	(Pa)
$\vec{F}$	-	Gravitational body force and external body forces	(N)
k_{eff}	-	Effective conductivity $(k + k_t)$	(W/m·K)
k_t	-	Turbulent thermal conductivity	(W/m·K)
$\vec{J}_j$	-	Diffusion flux of species j	($kg/m^2 \cdot s$)
h	-	Sensible enthalpy	(h^0)
Y_j	-	Mass fraction of species j,	(dimensionless)
G_k	-	Generation of turbulence kinetic energy due to the mean velocity gradients.	(dimensionless)
G_b	-	Generation of turbulence kinetic energy due to buoyancy	(dimensionless)
$C_{1\varepsilon}$	-	Constants for transport equations	(dimensionless)
$C_{2\varepsilon}$	-	Constants for transport equations	(dimensionless)
$C_{3\varepsilon}$	-	Constants for transport equations	(dimensionless)
S_k	-	User-defined source terms.	(dimensionless)
S_ε	-	User-defined source terms.	(dimensionless)
T_0	-	Air temperature without ventilation fan	(°C)
T_1	-	Air temperature with ventilation fan	(°C)

h	-	Convection heat transfer coefficient	($W/m^2 \cdot °C$)
P_{gauge}	-	Gauge pressure	(Pa)

Greek Symbols

ρ	-	Flow density	(kg/m^3)
ε	-	Turbulence Dissipation Rate	(m^2/s^3)
$\bar{\bar{\tau}}$	-	Stress tensor	(Pa)
$\vec{g}$	-	Gravitational body force	(m/s^2)
μ	-	Molecular viscosity	($Pa \cdot s$)

Abbreviations

AC	-	Air-conditioning
SWL	-	Short Wavelength
LWL	-	Long Wavelength
SIMPLE	-	Semi-Implicit Method for Pressure-Linked Equations
FDM	-	Finite Difference Method
RANS	-	Reynolds Averaged Navier-Stokes
FVM	-	Finite Volume Method
PDE	-	Partial Differential Equations
EV	-	Electric Vehicle
CFD	-	Computational Fluid Dynamics
2D	-	Two-dimensional
3D	-	Three-dimensional
s2s	-	Surface-to-surface
Re	-	Reynolds

TSV	-	Thermal Sensation Value
PPD	-	Predicted Percent Dissatisfied
HVAC	-	Heating, Ventilation and Air Conditioning
RNG	-	Renormalisation group
TEG	-	Thermoelectric generators
IR	-	Infrared
UV	-	Ultraviolet

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The air-conditioning (AC) system is the single largest auxiliary load on automobile engine. It was developed to provide an adequate cooling in a period of time from a hot soak condition (Rugh *et al*., 2001). The passenger compartment experienced peak soak temperatures regarding to maximum temperature reach, while soaking in the sun (Farrington and Rugh, 2000). According to Johnson (2002), during peak soak condition the AC system can draw up to 5 to 6 kW power from the vehicle's engine. This is equivalent to a vehicle being driven down the road at 56 km/hr. The study shows that the use of AC in a conventional vehicle increases the fuel consumption by 35% or drops fuel economy by 26%. By reducing the peak soak temperatures in the passenger compartment, it could lower the AC system power consumptions (Rugh *et al*., 2001). There are many ways for reducing the peak soak temperature such as solar reflective glazing, car shades, paint or rejecting the heat to the ambient by using active or passive ventilation of the passenger compartment while the car is parked in the sun (Bharatan *et al.*, 2007). The ventilation fan was identified as an efficient way for reducing the soak temperature inside the passenger compartment (Saidur *et al.*, 2009; Farrington and Rugh, 2000; Rugh *et al.*, 2007; Huang *et al*., 2005).

The need to reduce the heat loads that entered the passenger compartment has become an important issue nowadays. Recently, plenty works were reported on the use of ventilation fan in reducing the soak temperatures inside the passenger compartment. The researchers investigated the effect of ventilation fan on soak temperatures experimentally as well as Computational Fluid Dynamics (CFD) approaches. Generally, the experimental approaches were time and cost consuming (Sevilgen and Kilic, 2013). As a result, in the present study, the CFD approach is adopted in developing a numerical simulation tool to investigate the effects of using the ventilation fan on the air temperature and air-flow field inside the passenger compartment when the car was parked in the sun. A simplified passenger compartment model was developed using Gambit software. Meanwhile, a numerical simulation was developed using ANSYS FLUENT software and the simulation results were presented in steady–state condition in terms of contours of air temperature and air flow pattern.

1.2 Problem Statement

The single largest auxiliary loads on automotive engine were caused by the air-conditioner compressor (Haslinda *et al.*, 2012). During the peak load it can draw up to 5 to 6 kW power from the vehicle's engine and this is equivalent to the vehicle being driven down the road at 56 km/hr (Johnson, 2002). This could lead to increased fuel consumption. When the car parked in the sun, the soak air temperature inside the passenger compartment can rise up to 60°C (McLaren *et al.*, 2005). By reducing the air temperature inside the passenger compartment, it is very significant not only for passenger comfort but also to reduce the power consumed by the AC system. The equipment inside the passenger compartment will absorb the heat from the surrounding and make the passenger compartment hard to be cooled down within a short period of time. Consequently, a driver needs to turn on the AC system with the blower set to maximum before starting to drive in order to reduce the air temperature inside the passenger compartment to a comfortable level.

Reducing the air temperature inside the passenger compartment is very important to reduce the auxiliary loads of AC that could lead to saving the fuel consumption (Farrington *et al.*, 1998). To overcome this problem, the use of ventilation fan was identified as an efficient way for lowering down the air temperature inside the passenger compartment (Saidur *et al.*, 2009). To assess the effectiveness of ventilation fan, it is necessary to investigate the air temperature inside the passenger compartment. This can be achieved by means of performing the numerical simulation using CFD method. The numerical simulation was validated by comparing the air temperatures from the numerical simulation against the actual air temperatures data at two selected points obtained from the field measurement, when the car was parked in the sun from 12 pm to 3 pm.

1.3 Objectives of the Study

Accordingly, the objectives of this study are:

1. To estimate the air temperatures at two selected points without ventilation fan inside the passenger compartment when the car is parked in the sun.
2. To investigate the effect of ventilation fan on the air temperature and air-flow field inside the passenger compartment.
3. To perform a parametric study to investigate the influence of the ventilation fan location, number of the ventilation fans used and outlet air velocity at the ventilation fan on the air temperature and air-flow field inside the passenger compartment.

1.4 Scopes of Study

Towards achieving the objectives, several research scopes have been determined and listed as follows:

1. A three-dimensional (3D) model of Proton Saga BLM passenger compartment as the computational domain.
2. Ventilation fan as available in the market.
3. Steady-state operating condition, after the air temperature is reduced by the fan.
4. Without passenger.
5. Without AC system.
6. Thermal loading during parking in a sunny day condition.
7. Validation of the numerical simulation was done against the measured air temperature at two selected points obtained from the field measurement.

1.5 Thesis Outline

Chapter 2 discusses a review on the air temperature distributions and air–flow field inside the passenger compartment and method to reduce the air temperature inside the passenger compartment during parking condition.

Chapter 3 describes the development of the numerical simulation of passenger compartment model of Proton Saga BLM using CFD FLUENT software. The boundary conditions are specified accurately on the passenger compartment model based on the actual measurement. A validation of the numerical simulation was done by comparing the air temperatures from the numerical simulation against the actual air temperatures data at two selected points obtained from the field measurement. A parametric study is also described.

In Chapter 4, the results of the baseline case and parametric study are presented in terms of contours of air temperature as well as air flow patterns at steady-state conditions. The effects of the ventilation fan location, number of the ventilation fans used and the outlet air velocity at the ventilation fan on the air temperature and air-flow field inside the passenger compartment are discussed in details.

Finally, the conclusions and recommendations for the future study are discussed in Chapter 5.

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